Using Acoustic Emission to ease the task of condition monitoring

In principle it could be argued that acoustic emission and vibration techniques are the same except for the choice of detection frequency. In practice the differences are far reaching, and affect not only the transducer design and the signal processing, but above all, the signal-to-noise ratio of the detected signal. As a result, acoustic emission techniques are able to provide a different condition monitoring capability to that which is offered by vibration techniques, as Trevor Holroyd of UK-based company Holroyd Instruments Ltd explains.

Compared with vibration monitoring (VM), which involves the detection of elastic waves at audio frequencies, the acoustic emission (AE) technique involves the detection of elastic waves at ultrasonic frequencies. However, both techniques have followed quite different evolutionary paths towards their use in condition monitoring (CM).

Vibration techniques were originally developed to analyse the dynamic motion of objects and structures and at a later stage this technology was adapted in order to provide an 'instrumented' means of warning of mechanical faults in machinery. By contrast AE was originally developed as a method of non-destructive testing (NDT), whereby the 'sounds' that were generated by growing cracks were detected using sensitive surface contacting transducers. The names of Josef Kaiser, Hal Dunegan and Alan Green figure strongly in these early developments. Back in the 1960s it was very quickly realised that to improve the signal-to-noise ratio (SNR) of the detected signal it was necessary to use high frequency transducers. One of the earliest workers to apply this approach to condition monitoring was Harvey Balderston in the late 1960s (1).

However, the differences between AE and VM are not only historical. The improvement in SNR, which early AE researchers in the field of NDT noticed by moving to high frequency detection, is also applicable to condition monitoring.

Signal-to-noise ratio

By definition SNR is a relative measure of the strength of a wanted signal compared with the strength of the signal present in the absence of any wanted signal (that is, a wanted signal level V_S divided by background noise level V_N). This ratio can be expressed either linearly or more usually in a logarithmic scaling as dB (for example '10:1' or '20 dB') using the conversion for a voltage ratio of:

$$\text{SNR in dB} = 20 \log_{10} (V_S/V_N)$$

As the SNR drops, the wanted signal becomes increasingly corrupted by the noise component. When a signal has a low SNR it is necessary for it to be enhanced by an appropriate signal processing method in order for it to be detectable and for the required information to be extracted. It is a universal truth that signals with a high SNR are easier to process in order to extract the wanted information.

SNR of AE and vibration signals

There can be no doubt that if a machine fault exclusively generates a low-frequency vibration (for example, very low levels of out-of-balance or misalignment of a rotating machine) then by definition no high frequency (AE) signal will be detected, and for this reason VM would provide a vastly superior monitoring method to AE. (However, note that in practice, higher levels of misalignment and out-of-balance generate copious AE activity as the lubrication film is modulated by the cyclic stresses in the loaded zone).

Considering typical machinery defects that might occur in bearings and gears, the elastic wave source processes are primarily associated with impacts and friction. These are energy loss mechanisms which involve localised transient changes in the elastic stress within the bearing or gear material. Importantly these sources are broadband in the frequency domain extending from DC up to (typically) low MHz frequencies. Since the magnitude of the background noise signal usually falls away faster with increasing frequency than the wanted signal this leads to an improved SNR at high frequency.

To provide an easily understood illustration of this, an AE sensor and an accelerometer were mounted side by side on a plate. Small beads of solder were dropped onto the plate from a height of around 100 mm. The simultaneously detected signals from both the AE sensor and the accelerometer were digitally captured and are presented in Figure 1(a) and Figure (b). Closer analysis of these waveforms reveals

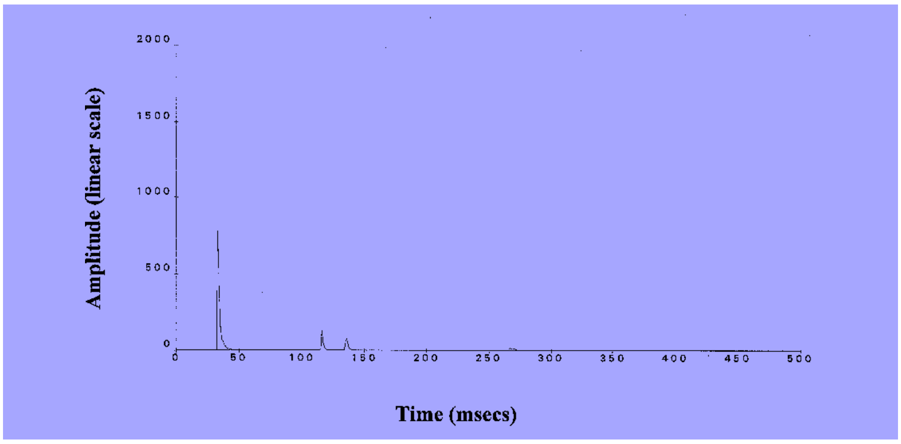

Figure 1(a). AE envelope signal during solder impacts.

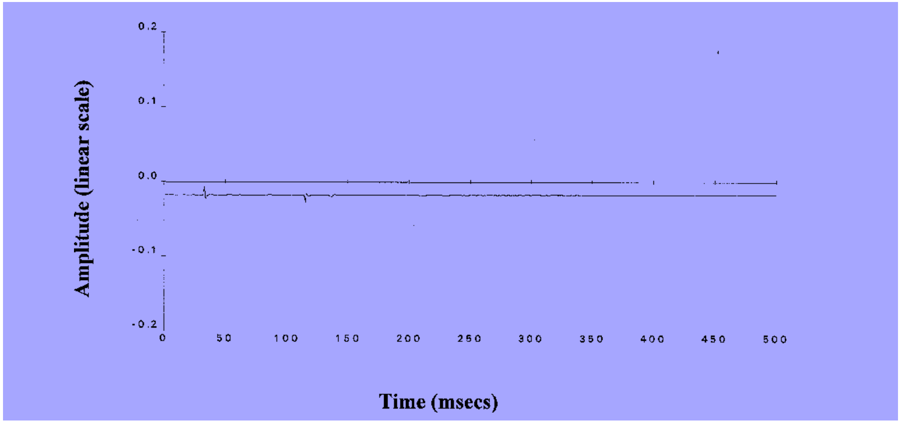

Figure 1(b). Accelerometer signal during solder impacts.

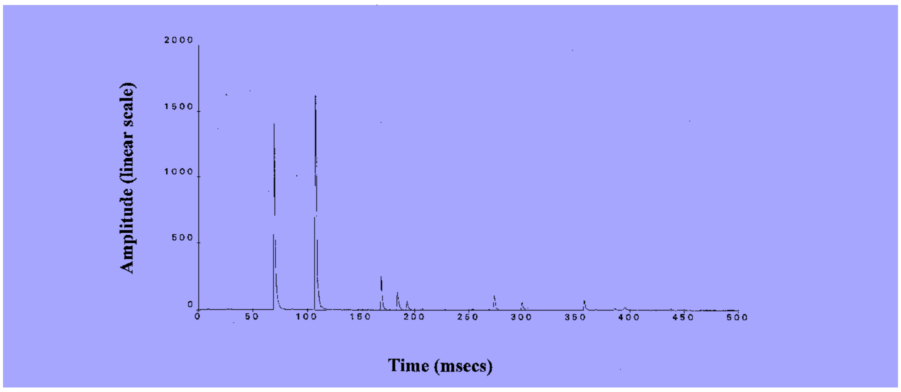

Figure 2(a). AE envelope signal during solder impacts with motor running.

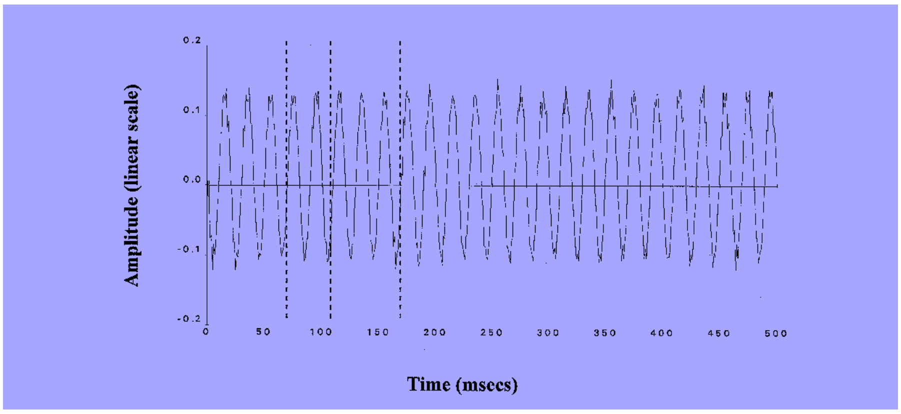

Figure 2(b). Accelerometer signal during solder impacts with motor running.

the peaks in the AE signal to have a SNR of approximately 60 dB while those in the vibration signal are at least 26 dB.

A motor was also mounted on this plate, and was switched on. This gave an immediate and sustained increase in the continuous background noise level to both the AE and vibration signals. The background noise level of the vibration signal increased by around 50 dB while that of the AE signal increased by around 20 dB. It is therefore not possible to detect the presence of solder bead impacts with the motor running, whereas they are still clearly detectable from the AE signal as evidenced by the simultaneous waveforms presented in Figure 2 (a) and Figure 2(b).

Improved SNR of AE signals

The benefit of the improved SNR of AE signals allows faults to be detected using simpler (time domain) signal processing. For VM to be effective on the shop floor it is essential to resort to the frequency domain and look for so-called defect frequencies present within the vibration signal. These frequencies correspond to the repetition frequencies of occurrences such as impacts from singular defects in the inner race, outer race or rolling element. There is no doubt that such analysis can result in a much improved SNR, allowing many defects to be detectable in an industrial environment. However, this is not without considerable cost (in terms of time and money) and increased measurement and interpretation complexity (requiring more highly skilled operators).

By contrast the presence of a defect is likely to be directly observable in the AE signal, usually because of the presence of signal transients known as AE bursts. The absence of these bursts is indicative of good condition while their presence reveals a problem. How the AE signal is best processed to make use of this fact varies between vendors and signal processing details are usually proprietary information. At Holroyd Instruments Ltd the AE signal, which is detected with a 100 kHz sensor, is enveloped and processed in terms of its mean level (scaled in terms of dB) and in terms of the proprietary Distress parameter which is a very sensitive indicator of the presence of defects in general, and has an almost universal interpretation for all rotating machinery (Table 1).

DISTRESS® VALUE	CONDITION
5 > Distress	Very Good
10 > Distress > 5	Generally Acceptable
Distress >10	Suspect

Table 1. At Holroyd Instruments Ltd the AE signal, which is detected with a 100 kHz sensor, is enveloped and processed in terms of its mean level (scaled in terms of dB) and in terms of the proprietary Distress parameter which is a very sensitive indicator of the presence of defects in general, and has an almost universal interpretation for all rotating machinery.

Leaving aside the experiences of third parties, Holroyd Instruments' interpretation has been tested by the company's staff on over 10 000 rotating machines of all types and sizes throughout industry in the UK. Figure 3 shows the monthly trend of Distress values on 4 pump bearings (two on each pumps). These values progressively increase until the bearings were re-greased. This gave a discernible improvement as shown by the reduction in the Distress values associated with each of the four bearings.

Since most bearing failures occur as a result of lubrication problems it is clear that such a simple means of lubrication assessment can have a very significant payback.

By contrast Figure 4 shows one-off readings taken at various points on the drive systems of two identical screw pumps. Using the standard interpretation of Distress it is clear that there is not a problem on the non-drive end (M/NDE) or drive end (M/DE) on either of the drive motors for the two pumps. However, on the gearboxes, which are pulley driven by the motors, it is clear that there is generalised dam-

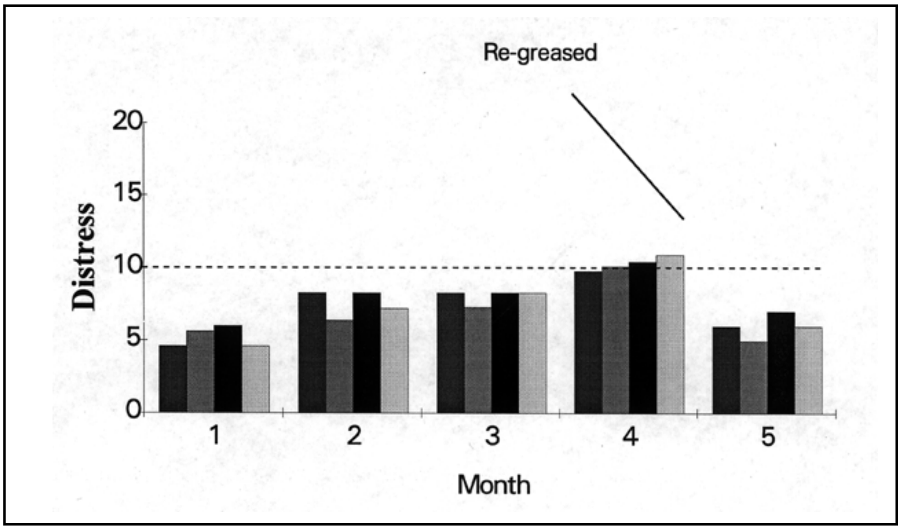

Figure 3. Trend of Distress values on 4 pump bearings.

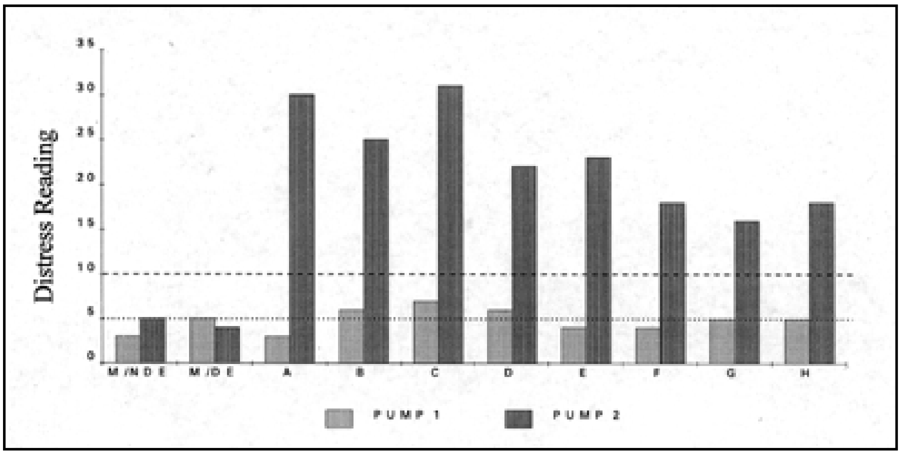

Figure 4. 'Snap-shot' view of Distress® values on two screw-pump drives.

age throughout the gearbox of pump 2 (points A to H). Investigation revealed that this gearbox had loosened its foundation mounting bolts, and it visibly moved when it was turned on because of the torque reaction of the large Archimedean screw to which it was rigidly mounted. This explained the reason for the generalised damage in this gearbox.

Figure 5 (a) and Figure (b) show the trend plot of Distress® and dB level on the lower bearing of a centrifugal water pump. Not only is there a high Distress® reading but the dB Level is progressively increasing which is indicative of accelerating deterioration. As a result of these indications, taken from the monthly measurements, this bearing was stripped down and it was found to have corroded as a result of a leaking seal.

After the bearing and the seal were replaced, the next monthly measurements show that the readings have dropped significantly. However, it can be seen that the Distress® reading only dropped to a value of 9 whereas it would be much more usual for the reading to be less than 5, following a successful repair. This higher than normal value of Distress® is likely to result from a minor problem which could have been easily resolved at the time of the repair, for example, over/under tightening, inadequate greasing, debris or water contamination of the grease. This highlights the opportunity for improving the effectiveness of maintenance if readings are not restricted to periodic intervals (for example once per month) but instead supplemented by other readings carried out at the time of the repair, and preferably by maintenance staff themselves.

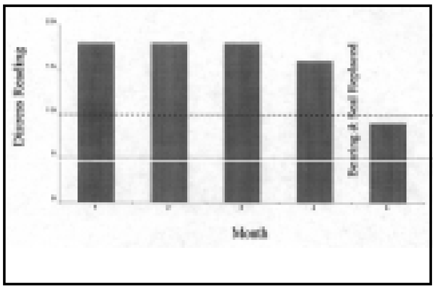

Figure 5 (a). Trend of Distress® value on water-pump bearing.

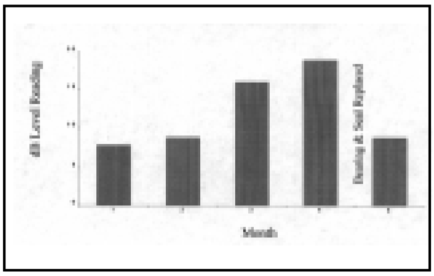

Figure 5 (b). Trend of dB level value on water-pump bearing.

Impact on CM strategies

Much of the thinking behind strategies for implementing CM seems to presume that CM methods are inevitably both time consuming and complicated and need to be part of an ongoing trend in order to be useful. As a result it is not uncommon for CM to be carried out either by specialist in-house departments or alternatively by external specialist service providers. However, the aim of CM is to provide timely information on deteriorating machine condition so that maintenance activities can be more efficiently conducted through better planning and by focusing attention where it is needed most.

In principle it is straightforward; the machine degrades, the CM specialist detects the problem and communicates this to maintenance personnel who then repair the machine.

In practice human nature often leads to strained lines of communications. The CM specialist may become frustrated by a lack of feedback from maintenance personnel on the nature of the faults indications, and from their viewpoint the members of the maintenance team may come to believe that the CM specialist is questioning their maintenance skills. In many organisations the result is a stand-off with simmering resentments and anything but a slick and efficient approach to asset management.

Where the CM team is in-house these problems can be eroded by having a policy of temporary attachments of maintenance personnel to the CM team. Unfortunately this approach is not applicable where CM is carried out by an external specialist firm. In addition, recent trends by many large organisations to contract out their maintenance function can make for a further weakening of the lines of communication between CM and maintenance functions.

It is clear that communication problems are reduced if the CM and maintenance functions are combined (whether this be in-house or external), but this can be done only if the CM techniques being employed are compatible with the data-taking and analysis skills which are available. It is in this regard that AE scores highly since experience suggests that maintenance staff regard it as a technique which is straightforward to use, and whose results are easy to interpret.

Concluding remarks

In this article, it has been argued that because of the improved SNR, which is associated with high frequency AE measurements, new opportunities exist for CM with a consequent beneficial impact on asset management strategies. At the heart of this argument is the belief that CM should be carried out as a matter of course by the maintenance department, and that CM specialists should be reserved for specialist CM tasks, for example, diagnostics. Finally, attention has been drawn to the usefulness of one-off measurements in addition to the more common trending approach.

In accordance with this argument it is our experience that the capabilities of the AE approach, which have been briefly illustrated here and which have been widely proven on the industrial shop floor, are enabling companies to rapidly benefit from a more direct knowledge of the condition of their machinery.

References

1. Balderston H.L. (1968) The Detection of Incipient Failure of Bearings, 28th ASNT National Fall Conference, Detroit, USA, 14-17 October 1968. (Reprinted in *Materials Evaluation*, June 1969, pp. 121-128.

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